GUIDANCE ON PROBABILISTIC-RISK-ASSESSMENT-BASED SEISMIC MARGIN ASSESSMENTS FOR NEW REACTORS

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) established Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," which provides requirements for early site permit (ESP), standard design certification (DC), and combined license (COL) applications. In this process, an application for a COL may incorporate by reference a DC, an ESP, both, or neither. This approach allows for the early resolution of safety and environmental issues. A COL review does not reconsider the safety issues that the DC and ESP processes have resolved. However, a COL application that incorporates a DC by reference must demonstrate that pertinent site-specific parameters are confined within the envelopes established by the DC. Although the NRC increasingly uses risk information and performance requirements to develop regulatory requirements and guidance, the agency recognizes that the design process of nuclear facilities is still inherently deterministic. To evaluate the robustness of new reactor designs, an assessment, such as a probabilistic risk assessment (PRA), based on systematic examinations of all probable accident events that can impact the safety performance of the reactors should be performed. This paper discusses the NRC staff's guidance on the safety review of PRA-based seismic margin assessments in DC and COL applications.

In addressing severe accident prevention and mitigation for new reactors, 10 CFR 52.47(a)(27) requires that the final safety analysis report for a DC application describe the design-specific PRA and its results. Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," issued June 2007, further states that the scope of this assessment should be a Level 1 and Level 2 PRA that includes internal and external hazards and that addresses all plant operating modes. However, the staff recognized that it is not practical for a DC applicant to perform a site-specific seismic PRA because a DC application would not contain site-specific seismic hazard information. As an alternative approach to a seismic PRA, the staff proposed a PRA-based seismic margin analysis in SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," dated April 2, 1993, and the Commission approved it in the corresponding staff requirements memorandum dated July 21, 1993. This analysis preserves key elements of a seismic PRA to the maximum extent applicable and estimates the design-specific plant seismic capacity in terms of sequence-level high confidence of low probability of failure capacities and fragility for all sequences that lead to core damage or containment failures up to approximately 1.67 times the ground motion acceleration of the design-basis safe-shutdown earthquake. Using this approach, the analysis can be used to evaluate the seismic risk for a DC to show that it is acceptably low.

The NRC staff has developed Interim Staff Guidance DC/COL-ISG-020, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors," dated March 22, 2010, to provide a clear process for the implementation and the safety review of PRA-based seismic margin assessments. This paper discusses key elements of DC/COL-ISG-020 with respect to DC applications and post-DC updating activities, including COL updates to incorporate site- and plant-specific features and post-COL verifications.

INTRODUCTION

The current practice for seismic design and analysis of the structures, systems, and components (SSCs) of nuclear power plants is generally recognized as conservative and robust. During the 1990s, U.S. Nuclear Regulatory Commission (NRC) requested licensees to perform [1] individual plant examination of external events. The results of these examinations demonstrated considerable seismic margins beyond the safe-shutdown earthquakes inherent in the designs of the current fleet of light-water reactors (LWRs) in the United States [2]. The nuclear industry estimated the seismic margins based on the staff's guidance for performing the individual plant examination of external events program [3], which permitted the use of either seismic probabilistic risk assessments (PRAs) or seismic margin assessments (SMAs). Although the SMA could not produce the same risk insights as the PRA, a well-executed SMA based on either the Electric Power Research Institute's (EPRI's) method [4] or the NRC's faulttree approach [5,6] can be used to evaluate the robustness and safety of the seismic design for an operating nuclear power plant, expressed in terms of a plant-level high confidence of low probability of failure (HCLPF) capacity.

However, extending these SMAs to the design certification (DC) applications for the standard designs of new reactors would not be appropriate. Because DC applications deal with generic designs without a specific site, information relating to site-specific seismic hazards and the site characteristics is not readily available. DC applications rely on assumed site parameters and seismic design basis in terms of the certified seismic design response spectra (CSDRS) for the seismic design. Without the benefit of the site-specific data and an as-designed and as-built plant necessary for establishing the success paths or sequences and the required SSC screening, the traditional SMAs cannot be well executed to their full extent.

As part of the licensing process under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" [7], to address PRA for new reactors, 10 CFR 52.47(a)(27) requires that the final safety analysis report (FSAR) for a DC application describe the design-specific PRA and its results. Regulatory Guide (RG) 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," issued June 2007 [8], further states that the scope of this assessment should be a Level 1 and Level 2 PRA that includes internal and external hazards and addresses all plant operating modes. As discussed above, the staff recognized that it is not practical for a DC applicant to perform a site-specific seismic PRA because a DC application would not contain site-specific seismic hazard information and as-built SSCs for a plant. The staff proposed a PRA-based seismic margin analysis in SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," dated April 2, 1993 [9], and the Commission approved it in the corresponding staff requirements memorandum dated July 21, 1993 [10]. The NRC expects the PRA-based SMA to perform a full system analysis to include all the SSCs that a seismic PRA normally includes. This analysis preserves key elements of a seismic PRA to the maximum extent applicable and estimates the design-specific plant seismic capacity in terms of sequence-level (HCLPF) capacities and fragility for all sequences that lead to core damage or containment failures up to approximately 1.67 times the ground motion acceleration of the safe-shutdown earthquake. This approach can provide a full evaluation of all relevant SSCs, including all safety functions. An analysis using this approach can be used to evaluate the robustness of the seismic design in order to show that he design has an acceptably low seismic risk.

For the 10 CFR Part 52 licensing process, the staff reviews the design-specific information during the DC review and site- and plant-specific information during the combined license (COL) application review. Accordingly, the applicant must carefully implement a PRA-based SMA to adequately reflect the true information available at different stages of the 10 CFR Part 52 licensing process. To this end, the staff developed Interim Staff Guidance DC/COL-ISG-020, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors," dated March 22, 2010 [11], to provide a three-tiered process for the implementation of a PRA-based SMA performed in support of a DC application and post-DC updating activities, including COL updates to incorporate site- and plant-specific features and post-COL verifications. This paper provides an overview of the implementation process and key staff positions described in DC/COL-ISG-020.

PROBABILISTIC-RISK-ASSESSMENT-BASED SEISMIC MARGIN ANALYSIS AND IMPLEMENTATION PROCESS FOR NEW REACTORS

A PRA-based SMA should provide a clear understanding of significant seismic vulnerabilities and other seismic insights to demonstrate the seismic robustness of a standard design in lieu of a full-fledged seismic PRA. Accordingly, the level of detail of a PRA-based SMA needs to be sufficient to gain risk insights to be used to identify and support requirements important to the design and plant operation. To this end, DC/COL-ISG-020 provides a three-tiered process for the PRA-based SMA implementation in licensing applications for new reactors. This three-tiered process includes (1) a PRA-based seismic margin analysis method and its implementation for DC applications, (2) site- and plant-specific updates of the DC PRA-based seismic margin evaluation for COL applications, and (3) post-COL licensee verification of as-designed and as-built plant seismic margin capacity preceding initial fuel load.

Each element of this process should be performed based on the technical information consistent with the application. Clear interface requirements between elements should be provided which are essential to ensure consistency and, therefore, the quality of the PRA-based SMA process. DC/COL-ISG-020 primarily relies on Part 5, "Requirements for Seismic Events At-Power PRA," of American Society of Mechanical Engineers/American Nuclear Society (ASME/ANS) PRA Standard ASME/ANS-RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," issued 2009 [12], as endorsed with conditions by RG 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment

Results for Risk-Informed Activities," Revision 2, issued March 2009 [13]. Because the ASME/ANS PRA standard was developed to address site- and plant-specific information, DC/COL-ISG-020 provides additional guidance to support the PRA-based SMA for the DC and COL applications. Note that RG 1.200 does not endorse the SMA methods for as-built and as-operated plants as described in Part 10, "Seismic Margin Assessment Requirements at Power," of the ASME/ANS PRA standard; these methods should therefore not be used for performing a design-specific PRA-based SMA.

GUIDANCE ON PERFORMING PROBABILISTIC-RISK-ASSESSMENT-BASED SEISMIC MARGIN ASSESSMENTS FOR DESIGN CERTIFICATIONS

Section 5.1 of DC/COL-ISG-020 provides a detailed process for performing a design-specific PRA-based seismic SMA that includes (1) an analysis of the design-specific system and accident sequences, (2) an evaluation of the seismic fragility, and (3) a determination of the plant-level HCLPF. The PRA-based SMA for DC applications should be guided by Part 5 of the ASME/ANS PRA standard as it relates to design-specific data for DCs. Given the generic nature of the DC applications, the additional steps described below should be followed.

Design-Specific System and Accident Sequence Analysis

The design-specific system and accident sequence analysis for a PRA-based SMA can be performed consistent with the Capability Category I requirements of Section 5-2.3 of the ASME/ANS PRA standard, with the exceptions that the analysis should not be based on site- and plant-specific information and that it should not rely on an as-built and as-operated plant. Screening of rugged SSCs can be performed based on the DC's CSDRS with its peak ground acceleration (PGA) scaled by a factor of 1.67. The basis for the screening needs to be adequately documented to ensure that the so-called "super element" does not control the plant seismic margin capacity. The analysis should consider random equipment failures, seismic interactions, and operator actions as applicable.

The plant systems analysis must focus on those sequences that lead to core damage or containment failures, including applicable sequences leading to the following containment failures: (1) loss of containment integrity, (2) loss of containment isolation, and (3) loss of function for the prevention of a containment bypass. In addition, the analysis should consider at-power (full-power), low-power, and shutdown modes. Note that the intent of the term "all sequences," as described in SECY-93-087, is to capture significant contributions to plant-level seismic risk. Notes to Table 5-2.3-2(a) of the ASME/ANS PRA standard provide some specific guidance on identifying seismic-caused initiating events based on past seismic PRA experiences. These initiators could be used as a starting point for developing associated seismic accident sequences for standard designs. In general, the design of SSCs for standard designs should have accounted for the risk-significant sequences for potential sites. This implies that failure of safety-related SSCs should most likely control the seismic sequences developed in the PRA-based SMA for a standard design. However, if the system analysis identifies a seismic sequence as important based on operating experiences in past seismic PRAs and if the seismic capacity of the sequence is controlled by nonsafety SSCs, further investigation may be required, which may lead either to design changes to upgrade these SSCs to safety-related SSCs or to an enhanced treatment to ensure an adequate sequence-level HCLPF capacity.

A seismic equipment list (SEL) should document the SSCs associated with the accident sequences that will require seismic fragility evaluation for determining sequence-level HCLPF. As inferred from the previous paragraph, the SEL developed for standard designs should most likely contain the safety-related SSCs.

Design-Specific Seismic Fragility Evaluation

The seismic fragility evaluation of SSCs in the SEL can be performed based on the Capability Category I requirements of Section 5-2.2 of the ASME/ANS PRA standard to the extent applicable as endorsed by RG 1.200 with the following exceptions:

- The seismic fragility calculations should be based on design-specific information provided within the scope of a DC application.
- The site- and plant-specific information would not be available during the review of the DC application and, therefore, cannot be relied on for computing seismic fragility.
- The seismic fragility calculation should use the response spectrum shape defined as the DC's CSDRS.

When applicants use generic data (such as test data, generic seismic qualification test data, and test experience data) to support the seismic fragility analysis, they should provide justification to demonstrate that the generic data are consistent and applicable to SSCs within the scope of the certified design application. For equipment on the SEL that must be qualified by seismic qualification tests, the applicant can use the procedure described in E.5 of EPRI Report 1002988, "Seismic Fragility Application Guide," issued in December 2002 [14], for developing fragilities. However, the probability of failure at a ground motion equal to 1.67 times the CSDRS, including consideration of testing uncertainties, should be less than 1 percent. Note that the numerical value for the plant HCLPF is determined at the sequence level, not at the component level. Therefore, given the component and system redundancies, only those components in the cutsets whose capacities are deemed to control the sequence-level HCLPF capacity must meet the numerical limit of 1.67 times the CSDRS.

In addition, the seismic demands on equipment defined in terms of required response spectra should include CSDRS-based seismic input; account for the structural amplifications caused by the supporting structures, including soil-structure interaction effects and supporting systems; and incorporate an additional seismic margin factor, as appropriate.

Plant-Level Capacity of High Confidence of Low Probability of Failure

In accordance with DC/COL-ISG-020, the HCLPF value for an SSC should be established in terms of the one-percent failure probability on the mean fragility curve. The HCLPF value should be expressed in terms of the PGA for consistency in the PRA-based seismic margin analysis process. The plant-level HCLPF capacity should be determined based on the sequence-level HCLPF values for all sequences as identified in the design-specific plant system and accident sequence analysis. The NRC considers the Min-Max method [5] acceptable for computing sequence-level HCLPF values. The plant-level HCLPF is therefore the lower bound of the sequence-level HCLPF values. The design-specific plant-level HCLPF value should be demonstrated to be equal to or greater than 1.67 times the CSDRS PGA.

Additionally, the design-specific PRA-based seismic margin analysis should be peer reviewed in accordance with Section 5-3 of the ASME/ANS PRA standard.

Activities after Design Certification

A PRA-based SMA for a DC provides results that include all identified seismically initiated accident sequences, the SEL with HCLPF values and associated failure modes, plant and sequence HCLPFs, and risk insights for seismic events. However, the PRA-based SMA is performed using the design-specific information within the scope of a DC application. Therefore, post-DC activities should ensure that the PRA-based SMA and the results remain valid and that they adequately reflect the site- and plant-specific information for a site for which the COL applicant incorporates the appropriate DC by reference.

In accordance with 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1), post-DC activities should include COL items that require the COL applicant to (1) update the design-specific plant system and accident sequence analysis to incorporate site-specific effects (e.g., soil liquefaction and slope failure) and plant-specific features (safety-related site-specific structures), as applicable, (2) update the SEL with HCLPF values and associated failure modes to adequately reflect the site-specific effects and plant-specific features of the COL site, and (3) demonstrate that the COL application maintains the design-specific plant-level HCLPF capacity. For soil-related failure modes, the site-specific ground motion response spectra (GMRS) can be used for HCLPF calculations.

The activities performed after a DC should also include postlicensing activities to verify the plant- and sequence-level HCLPF capacity, which should be based on the as-designed and as-built configuration of the plant before the initial loading of fuel. Note that DC applicants can propose any of the options that Early Site Permit (ESP)/DC/COL-ISG-015, "Interim Staff Guidance on Post-Combined License Commitments," dated January 21, 2010 [15], identifies for postlicensing activities.

UPDATING BY COMBINED LICENSE APPLICANTS

In accordance with 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1), a COL applicant must describe the plant-specific PRA and the results in its FSAR. In addition, the site-specific PRA must use the PRA information for the referenced DC and must be updated to account for site-specific design information. For a COL application that incorporates a DC by reference, the COL applicant must implement the COL action items included in the respective DC and must update the DC's PRA-based SMA to adequately incorporate site- and plant-specific information for the COL site. To this end, Section 5.2 of DC/COL-ISG-020 outlines the steps for the COL applicant to update the DC PRA-based SMA, as described below.

Updating the System and Accident Sequence Analysis

The COL applicant must update the design-specific system and sequence analysis to reflect the site- and plant-specific information of the COL. The update should focus on the fault space systems analysis model for the plant to account for site-specific effects and plant features. The site-specific features may include site-specific effects such as seismically induced liquefaction settlements, slope stability, foundation failure, and relative displacements and may include plant specific features such as the underground piping, intake structure, intake tunnel, and ultimate heat sink. A screening process similar to the DC analysis can be employed to assist with the update. Accordingly, the COL applicant can perform the screening of rugged site- and plant-specific information for the COL site based on the site GMRS with the PGA scaled by a factor of 1.67, following the guideline provided in HLR-SHA-G1 of Section 5-2.1 of the ASME/ANS PRA standard. However, the update should not rely on an as-built and as-operated plant because the plant is not constructed at the time of the COL application.

The updated analysis incorporates the site-specific effects and plant-specific features that cannot be addressed using standalone evaluations in the sequence-level system model. In general, these effects and structures would relate to site-specific structures that affect the probabilities of events in the event sequences. For these cases, the calculation of sequence- and plant-level HCLPF seismic margin factors for the updated system model accounts for the probabilities of failure for these site-specific effects and plant-specific features.

As the accident sequences are updated, additional SSCs may be identified and should be included in the updated SEL.

Updating the Seismic Fragility Evaluation

A COL applicant that incorporates the DC by reference does not need to update the seismic fragility calculations performed for the DC space SSCs (1) if the site-specific soil effects on the seismic fragility of the pertinent SSCs are deemed not to control the plant-level HCLPFs with adequate justification and (2) if the COL application demonstrates that the DC CSDRS envelops the COL site GMRS. For the latter condition, the comparison should be made at the free-field ground surface.

For those SSCs susceptible to the soil failures of the COL site, updating the seismic fragility of these SSCs is necessary to reflect the actual soil effects of the COL site. In addition, the estimate of the seismic fragility also requires SSCs that are identified and added to the updated SEL as a result of the update to the system and accident sequence analysis to incorporate site-specific effects. To this end, the seismic fragility evaluation of these SSCs can be estimated based on the Capability Category I requirements in Section 5-2.2 of the ASME/ANS PRA standard to the extent applicable and as endorsed by RG 1.200. However, the fragility calculations cannot be based on an as-built and as-operated plant because the plant is not constructed at the time of a COL application.

When the seismic fragility analysis is performed considering site-specific effects and plant-specific features, the response spectrum shape should be based on the COL site-specific GMRS. Fragility for seismically induced liquefaction can be developed using a fragility method described in Section G of EPRI Report 1002988 [14], together with the limit state defined in terms of the allowable settlements specified in the design control document for the referenced DC. Alternatively, the limit state may be defined in terms of the consequences of settlement on the site configuration of safety-related SSCs, including site layout, umbilicals between structures, and buried pipes and concrete electrical ducts, with adequate justification.

When applicants use generic data (such as test data, generic seismic qualification test data, and earthquake experience data) to support the seismic fragility analysis, they should provide justification to demonstrate that the generic data are consistent and applicable to the site- and plant-specific information concerning the SSCs provided within the scope of a COL application.

Updating the Plant-Level High Confidence of Low Probability of Failure Capacity

The COL application should update the plant-level HCLPF capacity expressed in terms of the PGA based on the sequence-level HCLPF values for all sequences as updated to incorporate site-specific effects and plant-specific features of the COL site. The NRC considers the Max-Min method acceptable for computing sequence-level HCLPF values. Therefore, the plant-level HCLPF is the lower bound of the sequence-level HCLPF values. The plant-specific plant-level HCLPF value should be demonstrated to be equal to or greater than 1.67 times the site-specific GMRS PGA.

If the plant-level HCLPF capacity is estimated at less than 1.67 times the site-specific GMRS, the NRC considers one of the following two options acceptable: (1) the COL applicant identifies the affected SSCs and upgrades their capacity to ensure that the plant-level HCLPF capacity is maintained at the level of 1.67 times the GMRS PGA, or (2) the COL applicant performs a full convolution of sequence fragility for all sequences with a potential to lead to core damage with the mean hazard curve to develop risk metrics to demonstrate that the seismic risk is acceptably low for the licensed plant. Note that the COL applicant can use the guideline provided in HLR-SPR-E1 of Section 5-2.3 of the ASME/ANS PRA standard to determine the number of sequences that are adequate for quantifying core damage frequency. The NRC staff would review the analysis associated with the second option on a case-by-case basis.

ACTIVITIES AFTER ISSUANCE OF COMBINED LICENSE

The licensee must verify the capacity of the plant SSCs to demonstrate that the plant- and sequence-level HCLPF capacity is consistent with the COL. The licensee must perform the verification based on the as-designed and as-built configuration of the plant. EPRI-NP-6041-SL, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," issued in 1991 [4], describes a plant walkdown process that can be used for the capacity verifications.

The licensee should complete the verification activities before the initial loading of fuel to confirm that the as-designed and as-built plant-level HCLPF capacity is at the level of 1.67 times the site GMRS PGA or at the values that were reviewed and approved for the licensee. The licensee should document the verification findings and make the documentation available for inspection. After completing the as-built verification of seismic fragility target values for applicable seismic SSCs, the licensee should update the FSAR for the licensed plant to reflect the as-built values.

COMPLETENESS IN DOCUMENTATION

The FSAR referenced in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Chapter 19, "Severe Accidents," issued June 2007 [16], should conform to the guidance in Appendix A to Section C.I.19 of RG 1.206 and apply relevant requirements in Part 5 of the AMSE/ANS PRA standard for documentation and should include the elements listed below.

For a DC application, Chapter 19 of the FSAR should include the following 11 elements:

(1) seismic accident initiation events
(2) summary of the operating modes, accident sequences, and event/fault trees and damage levels considered in the analysis
(3) definition of the response spectrum shape used for the fragility analysis of SSCs, accident sequences, and the plant
(4) identification of the methods used to calculate sequence- and plant-level HCLPFs for the sequences, operating modes, and damage levels considered
(5) table with the capacities (e.g., in terms of the median and logarithmic standard deviation of the fragilities) for the SSCs in the SEL
(6) summary description of the methods used for the derivation of the component fragilities, including a summary of how the component probability of failure is related to the ground motion parameter
(7) for equipment listed in the SEL that is qualified through tests, a description of the procurement specifications and the determination of the seismic demands to the equipment to ensure the appropriate HCLPF capacity of the procured equipment
(8) risk-significant SSCs, dominant cutsets and sequences, and seismic event/fault trees
(9) sequence- and plant-level HCLPF capacities for the operating modes and damage levels
(10) summary of independent peer reviews
(11) analysis assumptions, COL action items, interface items, and postlicensing activities

For a COL application that references a certified design, Chapter 19 of the FSAR should contain the following eight elements:

(1) updated seismic-initiating events based on available site- and plant-specific information if the COL application references a DC
(2) identification of site-specific effects and plant-specific features, including those that correspond to single-event sequences
(3) summary of the update of the systems model that incorporates site-specific plant features and site-specific effects if the COL application references a DC
(4) table with the HCLPF capacities for the effects and features in item 2 of this list expressed in terms of the site GMRS
(5) a list of cases (e.g., sequences) for which there is no significant change from the certified design PRA-based seismic margin analysis
(6) updated sequence- and plant-level HCLPF capacities for those cases with a significant change from the certified design PRA-based seismic margin analysis, if any
(7) site hazard information if risk metrics are calculated
(8) postlicensing activities and interface requirements that must be verified before initial fuel loading

CONCLUSION

This paper describes interim staff guidance that the staff developed to provide an implementation process for performing the PRA-based SMA in support of DC and COL applications. DC and COL applications that use the 10 CFR Part 52 licensing process should demonstrate the robustness of the seismic design and analysis in the certified design. If the implementation process as described in the staff guidance is followed closely, the robustness of the seismic design and analysis of the certified design can be adequately measured using the PRA-based SMA performed for the DC and subsequently updated by the COL applicants to incorporate the site- and plant-specific features. Consequently, adequate safety margin in the seismic design of the standard plant is ensured.

DISCLAIMER NOTICE

The NRC staff prepared this paper. It may present information that does not currently represent an agreed-upon NRC staff position. The findings and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the NRC.

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